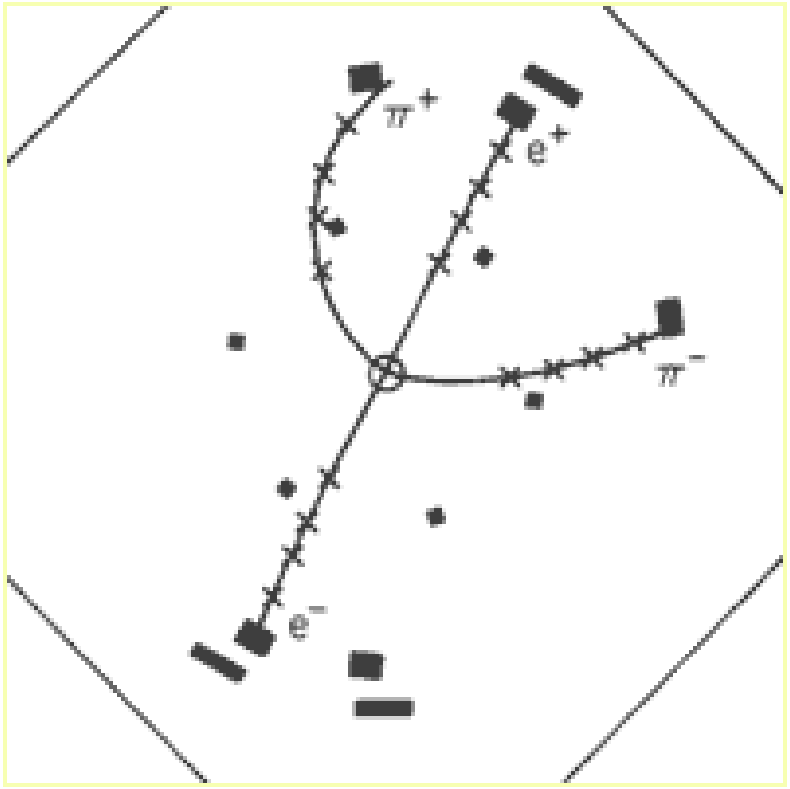
Measurement of an Excited Charmonium State and the Study of J/ψ Polarization in PHENIX Experiment at RHIC

Celebrating the November Revolution!



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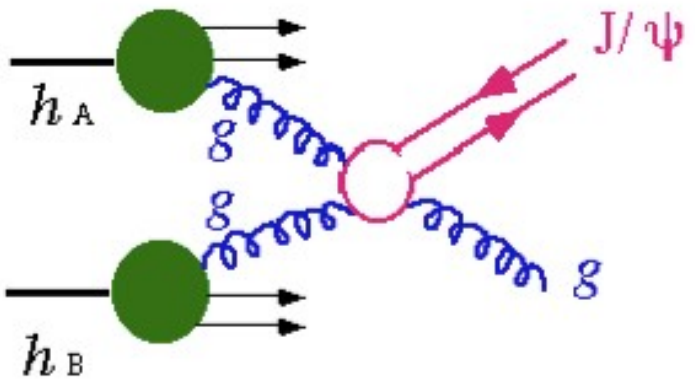
Quarkonia production in pp collisions

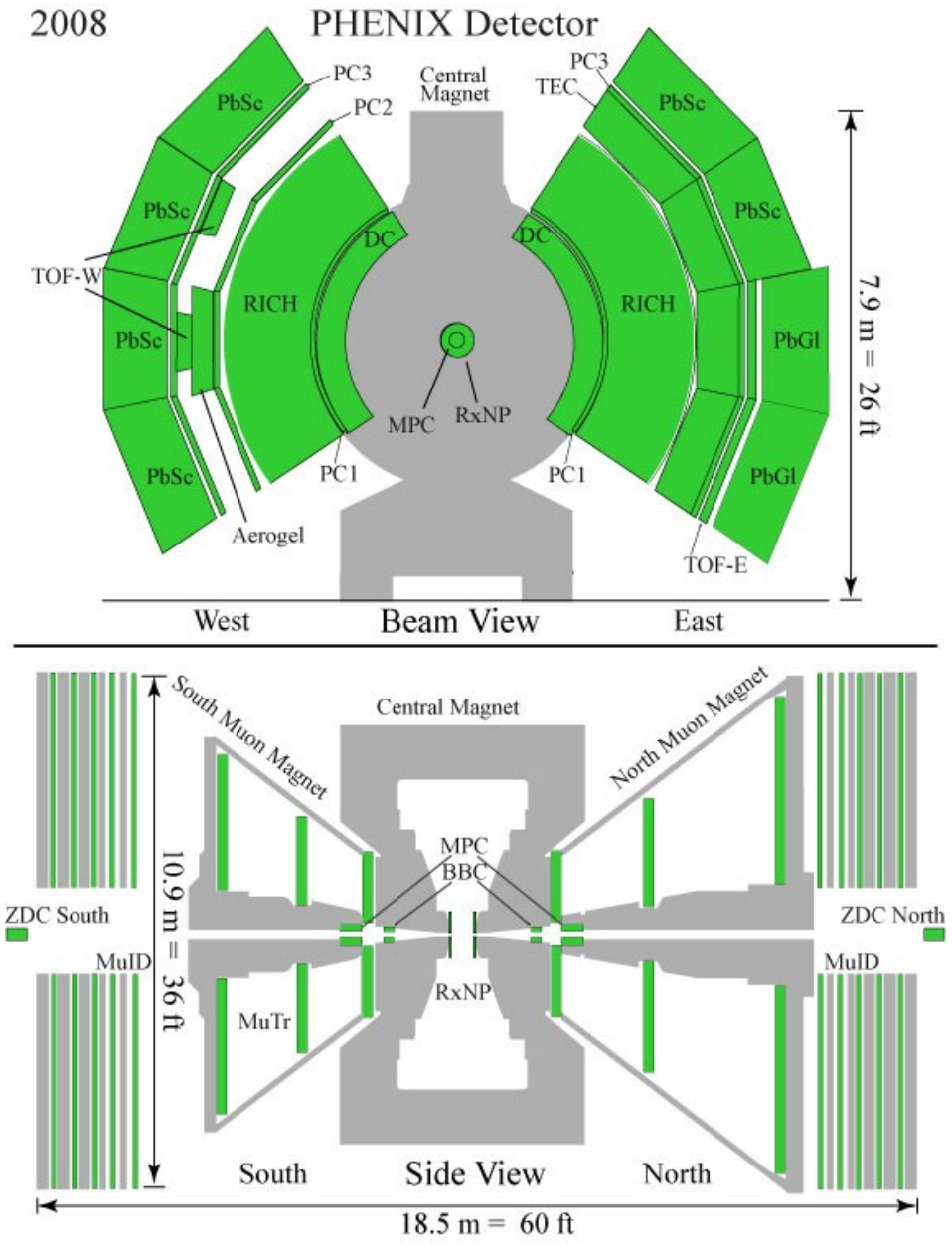
•Heavy quarks predominantly generated in hadronic collisions via gluonic diagrams and production can be calculated in perturbative QCD.



•Details of quarkonia hadronization process remain unclear. Color neutralization is a non perturbative process and several models have been proposed:

- NRQCD;
- Color Evaporation Model;
- Color Singlet Model.

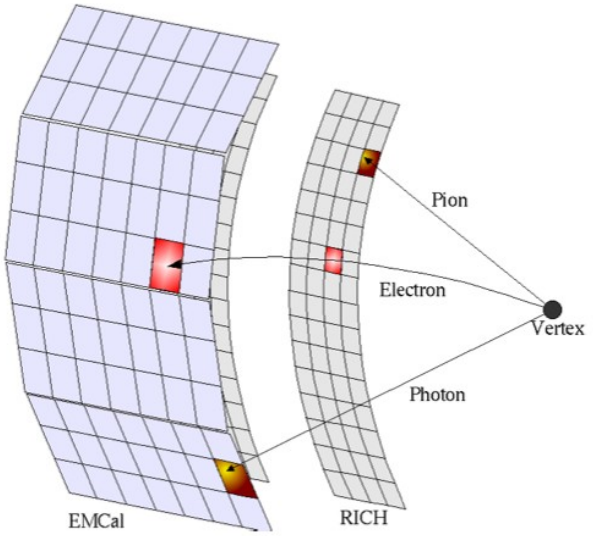
Charmonium Signals at PHENIX

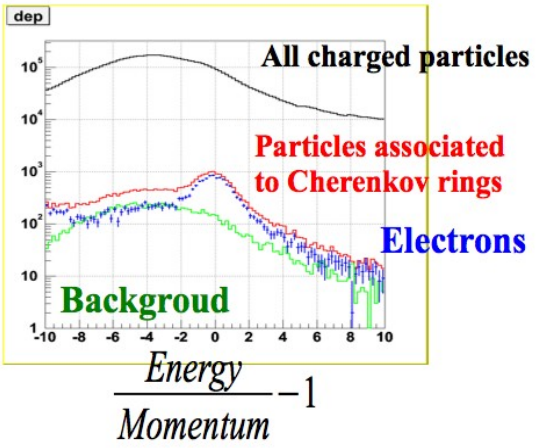


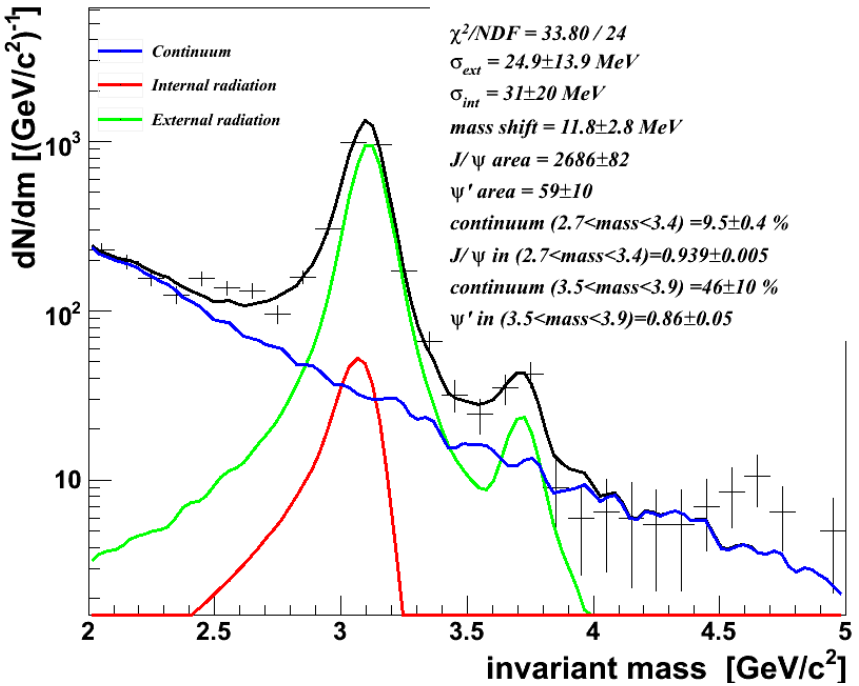
- Central Arms: Hadrons, photons, electrons;
  - $J/\psi \rightarrow e^+e^-$; $\psi' \rightarrow e^+e^-$; $\chi_c \rightarrow e^+e^-\gamma$;
  - $|\eta|<0.35$;
  - $p_e > 0.2$ GeV/c;
  - $\Delta\varphi=\pi$(2 arms x $\pi/2$)
- Forward rapidity Arms: Muons
  - $J/\psi \rightarrow \mu^+\mu^-$
  - $1.2<|\eta|<2.2$
  - $p_\mu > 1$ GeV/c
  - $\Delta\varphi = 2\pi$

Electron Identification at PHENIX

- Electron candidates are charged tracks identified by RICH and with position and energy measured by EmCal;
- Dielectron events are selected by additional logical trigger;
- The numbers of J/ψ and ψ ' candidates are obtained by counting the unlike-sign dielectron pairs in a fixed mass window after subtracting the like-sign pairs.







J/Ψ [2.7-3.4] GeV/c^2
Ψ' [3.5-3.9] GeV/c^2

J/ψ cross section at PHENIX

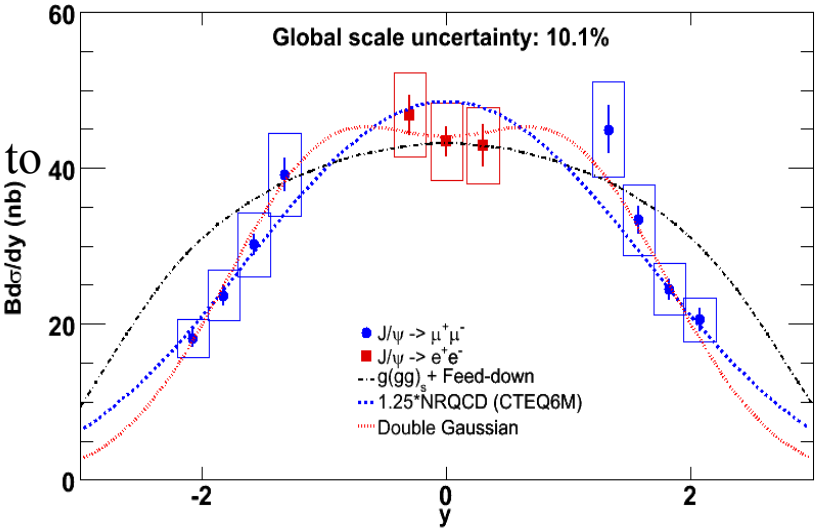
PHENIX Run5 p+p data [PRL98:232002,2007] began to constrain shape of cross section vs rapidity & p_T

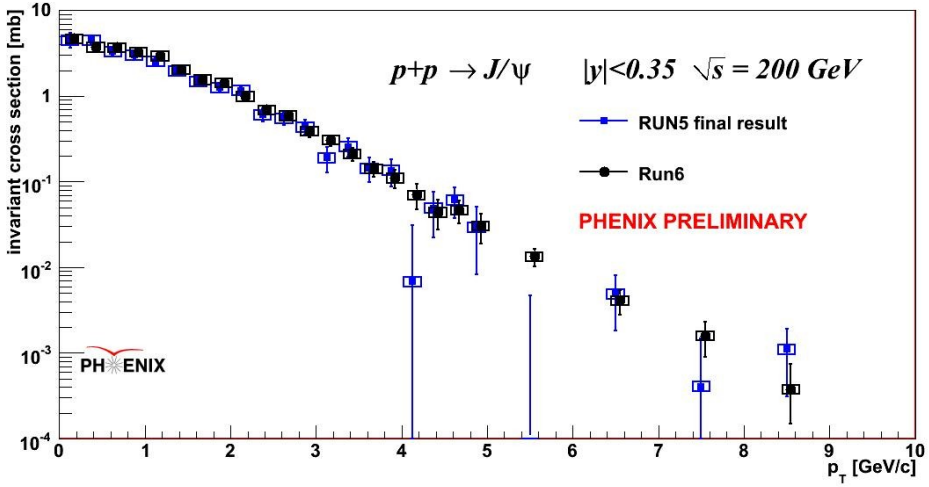
Total cross section calculated by integration of different fits to y dependence

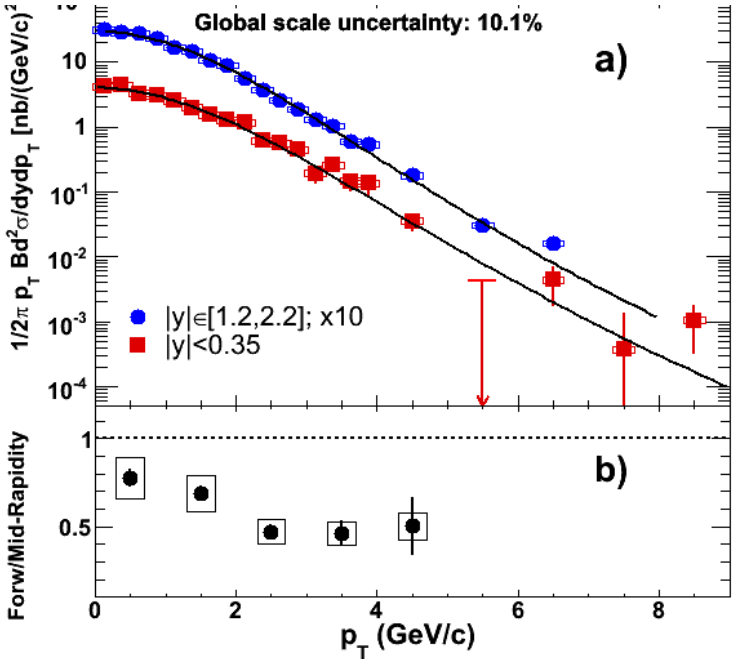
Inclusive measurement: includes feed down

Different models fit to the p+p data returning a total cross section:

BR σ(p+p->J/ψ+X)= 178 ± 3(stat) ±53 (sys) ±18 (norm) nb





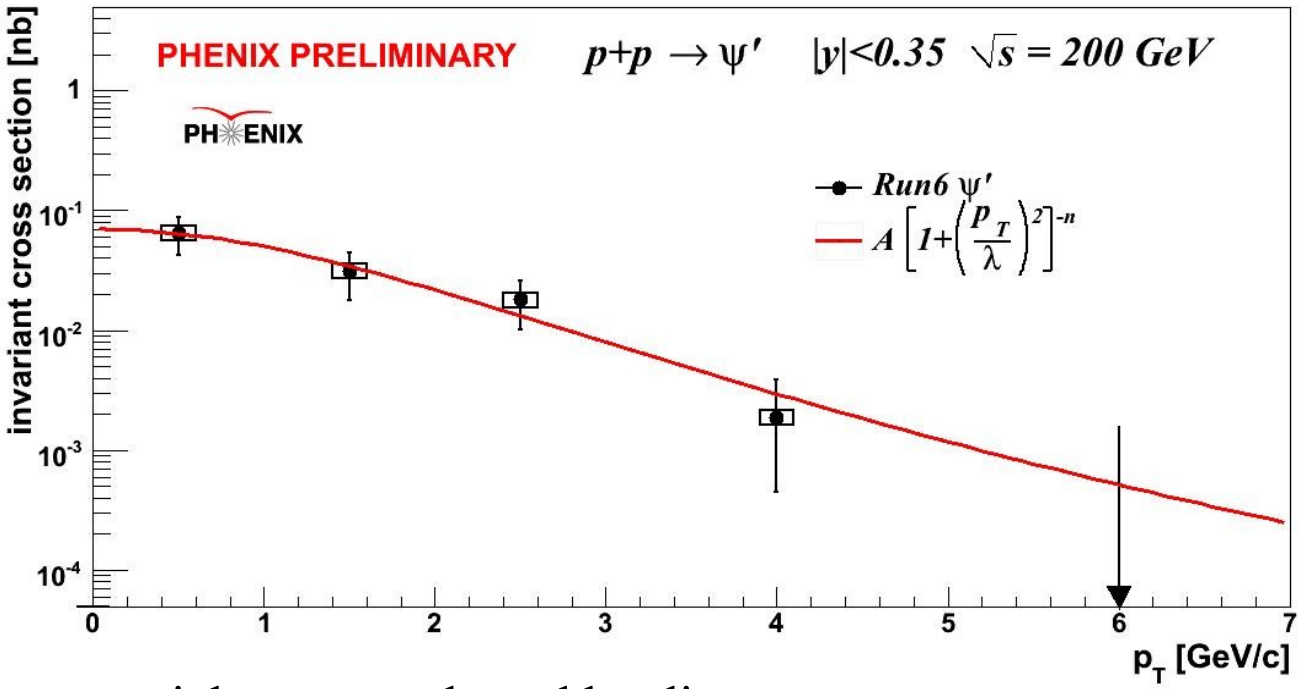


Brand new yield measurement from larger luminosity Run6 agrees with published results!

$$B\frac{d\sigma_{J/\psi}}{dy}\Big|_{|y|<0.35} = 45.3 \pm 1.0(stat) \pm 5.4(sys) \pm 4.5(global)nb$$

Run5 Result = 44.0 ± 1.4(stat) ± 5.7(sys) ± 4.4 (global) nb

ψ ' cross section at PHENIX



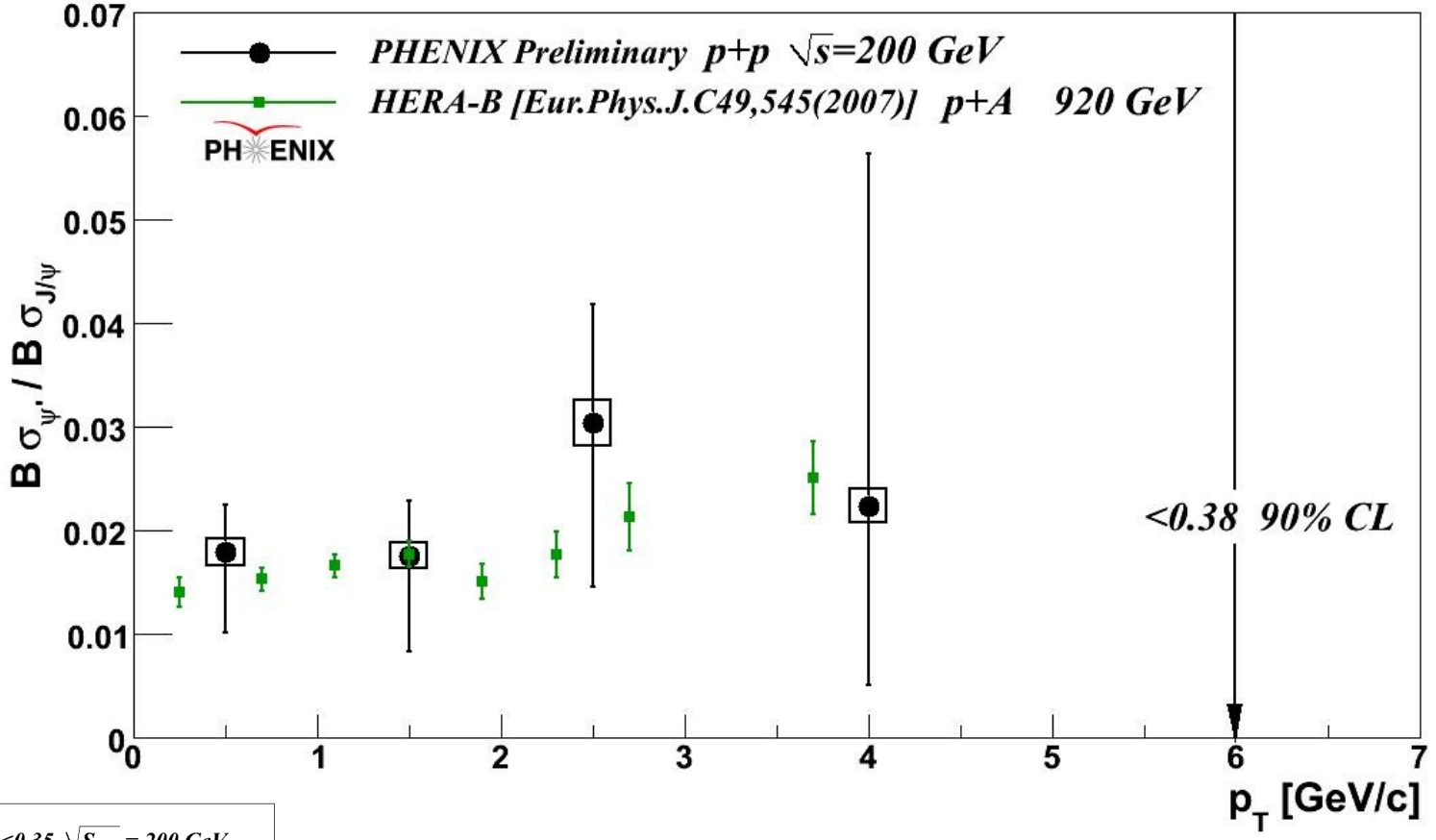
•The number of ψ particles were selected by direct counting after like sign background subtraction.

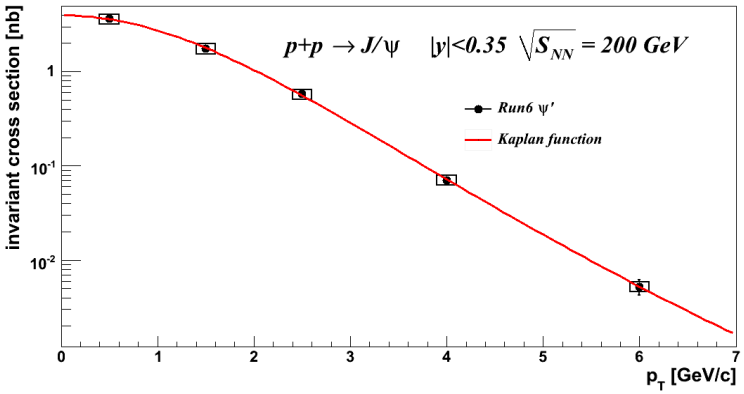
•The e+e- invariant mass distribution was fitted with templates generated from Monte Carlo simulation of continuum contribution (correlated D and B mesons and Drell-Yan), besides internal and external radiations.

p_T [GeV/c]	$d\sigma_{\psi'}/dydp_T\|_{y=0}[nb]$
0-1	0.065 ± 0.022(stat) ±0.009 (corr)
1-2	0.031 ± 0.013 (stat) ±0.003 (corr)
2-3	0.018 ± 0.008 (stat) ±0.003 (corr)
3-5	$0.0019\ ^{+0.0020}_{-0.0015}$ (stat) ±0.0003 (corr)
5-7	< 0.0015 90% CL

$$B_{\psi' \to e^+e^-}\sigma_{\psi'}|_{|y|<0.35}\,(p_T < 7GeV/c) \;=\; 0.88^{+0.30}_{-0.20}(stat) \pm 0.12(sys)\ nb$$

ψ' to J/ψ cross sections ratio measurement at PHENIX



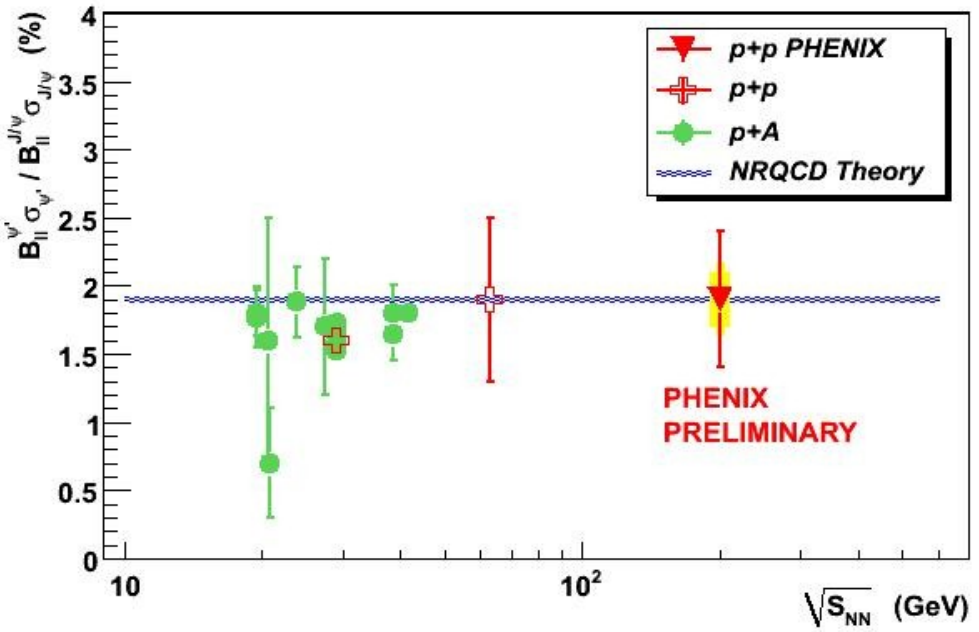


$$B_{J/\psi\to e^+e^-}\sigma_{J/\psi}\big|_{|y|<0.35}(p_T < 7GeV/c) = 41.0 \pm 0.9(stat) \pm 4.9(sys)\ nb$$

0-1	$0.0179\ ^{+0.0046}_{-0.0078}$ (stat) ±0.0013 (corr)
1-2	$0.0176\ ^{+0.0053}_{-0.0093}$ (stat) ±0.0013 (corr)
2-3	$0.0304\ ^{+0.0115}_{-0.0159}$ (stat) ±0.0022 (corr)
3-5	$0.0223\ ^{+0.0340}_{-0.0173}$ (stat) ±0.0016 (corr)
5-7	< 0.38 90% CL.

(BRΨ'->e+e-)σ(Ψ') / (BRJ/Ψ->e+e-)σ(J/Ψ)= 0.019±0.005±0,002

Feed down fraction of J/ψ from ψ' in PHENIX



- PHENIX preliminary
  - BR(ψ'→e⁺e⁻)σ(ψ')/BR(J/ψ→e⁺e⁻)σ(J/ψ) =0.019 ± 0.005 (stat) ± 0.002 (syst)
- PDG 2008 values
  - BR(J/ψ→e⁺e⁻)=5.94 ± 0.06%
  - BR(ψ'→e⁺e⁻)=0.743 ± 0.018%
  - BR(ψ'→J/ψ+X)=56.9 ± 0.9%
- σ(ψ')/σ(J/ψ)=0.15 ± 0.04
- Feed-down fraction of J/ψ from ψ' is **0.086 ± 0.025**.

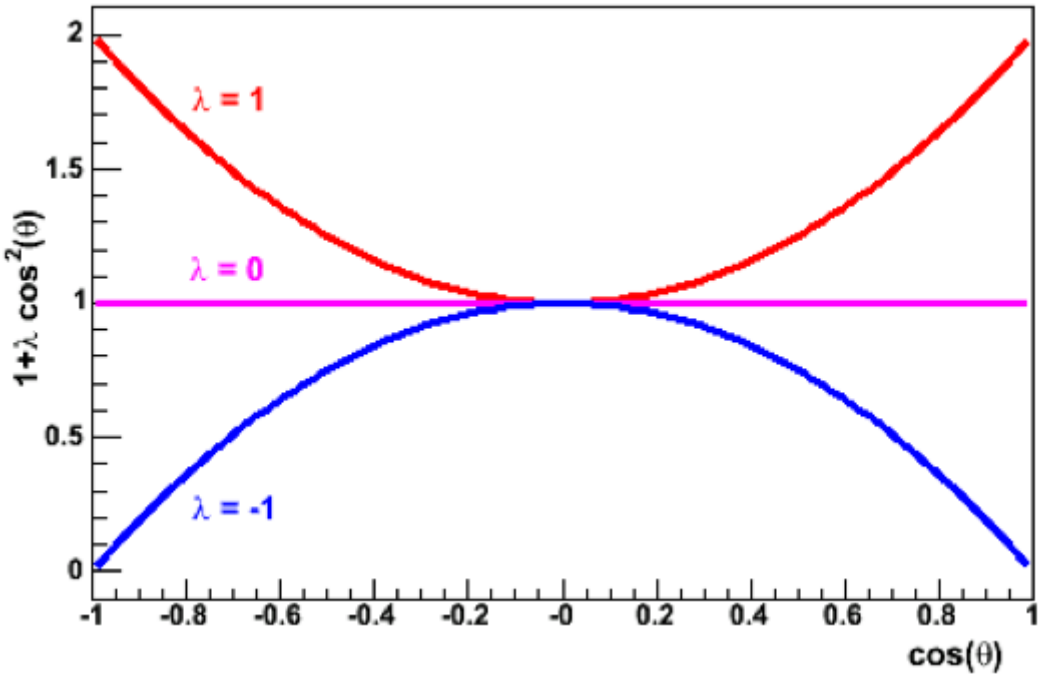
- R(ψ') =8.6±2.5% PHENIX [QM08];
- R(ψ') =8.0±2.0% from the lattice [Phys. Rev.D64:094015]
- R(ψ') =8.1±0.3% from average of world data [hep-ph/0809.2153v1]

Why polarization matters...

- Measurements of polarization (the commonly used term to denote spin alignment) provide one of the most significant tests of models of charmonia production:
  - Color Singlet Model : transverse polarization: [Phys. Rev. D 51(1995) 3332];
  - NRQCD: transverse polarization at high pT [Phys. Rev. D 62 (2000) 094005]
  - Color Evaporation Model : no polarization [hep-ph/9403387]
  - K_T factorization: longitudinal polarization at high pT [Phys. Rev. D 66 (2002) 114003];
  - s- channel cut contribution to J/ψ hadroproduction: at low and mid-range p_T at Fermilab and RHIC: longitudinally polarized [Phys. Rev. Lett. 100, 032006 92008]

The observable

- J/ψ polarization can be studied through the angular distributions of the decay lepton pairs.
- θ is the angle between the lepton momentum in J/ψ rest frame, (helicity frame) and J/ψ momentum in the laboratory frame.

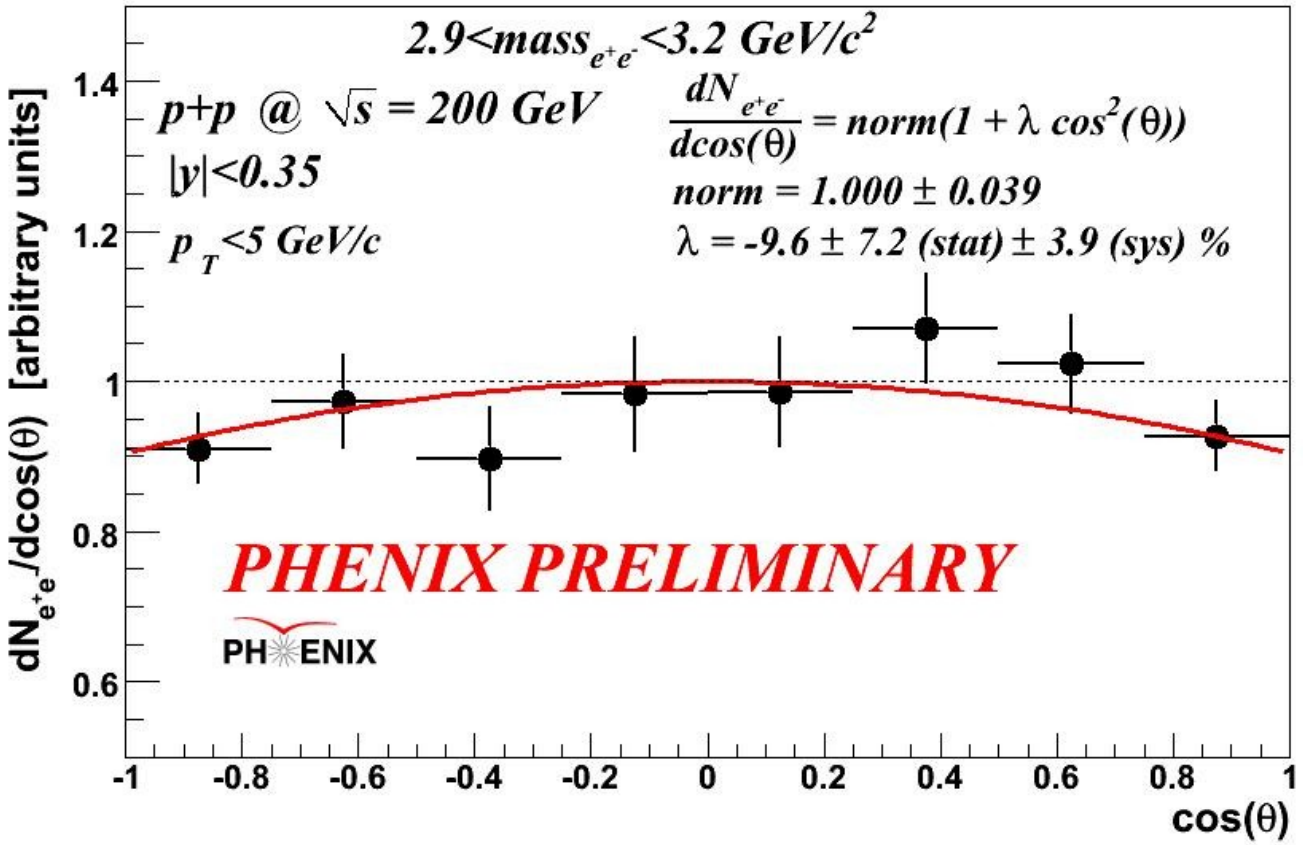


Parametrization of the angular distribution ⟶ $\frac{d\sigma}{dcos\theta} \propto 1 + \lambda cos^2\theta$

λ = 1 (transverse polarization)
λ = 0 (no polarization)
λ = -1 (longitudinal polarization)

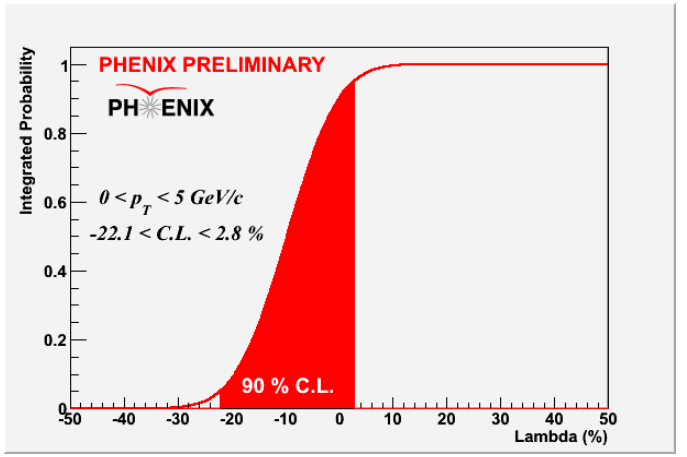
J/Ψ polarization parameter measurement in pp collisions at PHENIX

p_T<5 GeV/c

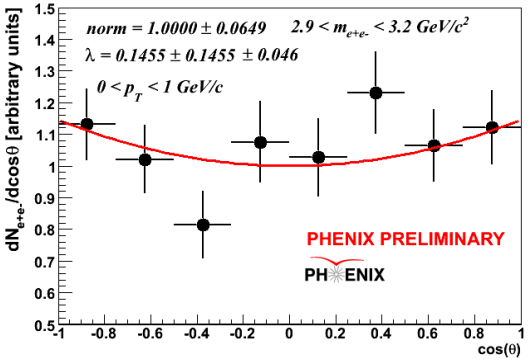


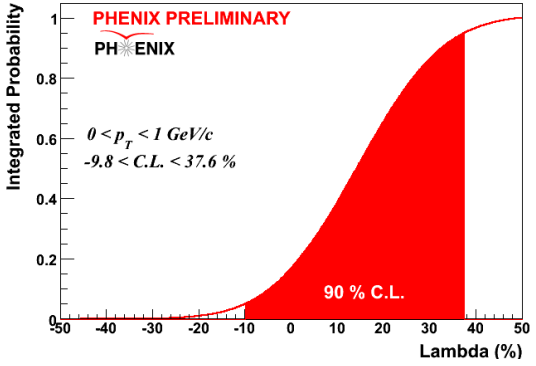
$\lambda_{J/\Psi}$ = -9.6 ±7.2(stat)±3.9(sys)%

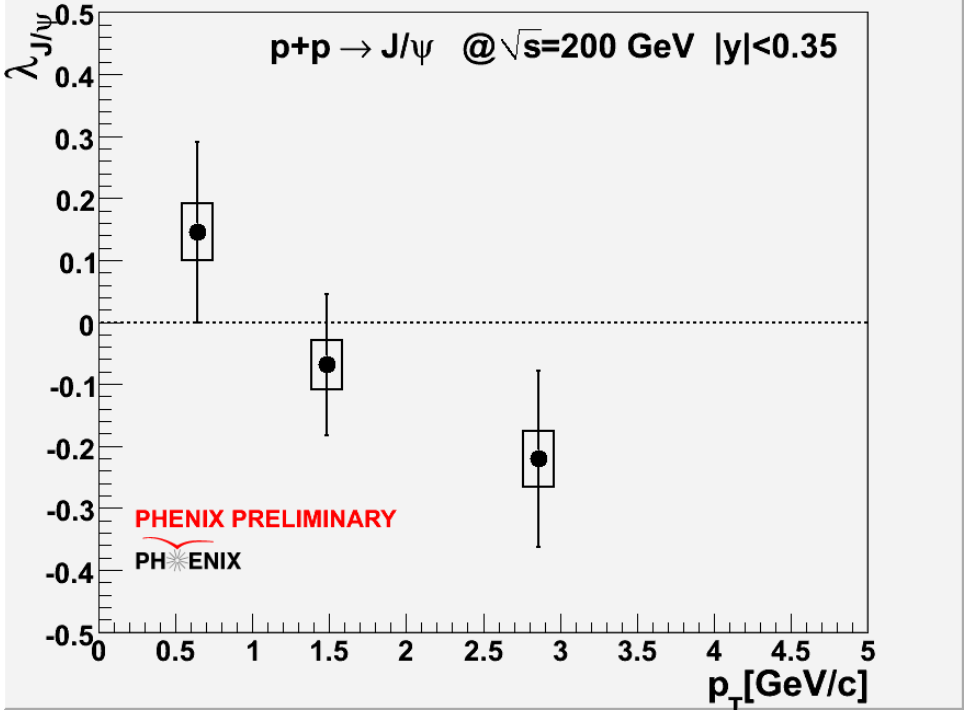
- J/ψ candidates were selected in the mass window [2.9-3.2] GeV/c^2 after same sign pairs background subtraction .
- The acceptance corrected cosθ distribution is the measured distribution divided by the acceptance obtained from simulation.

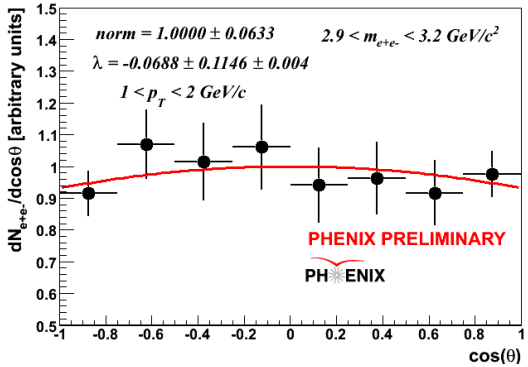


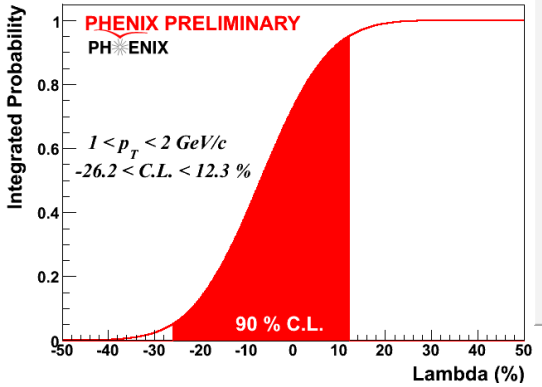
p_T dependent J/ψ polarization parameter in pp collisions at PHENIX

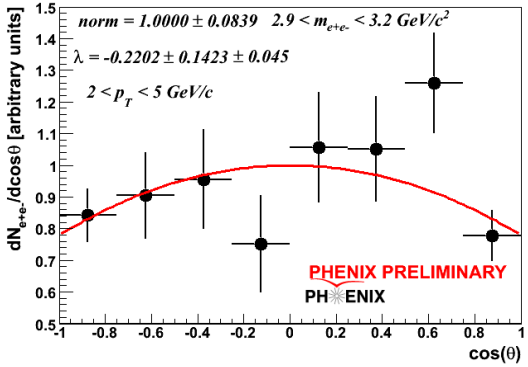


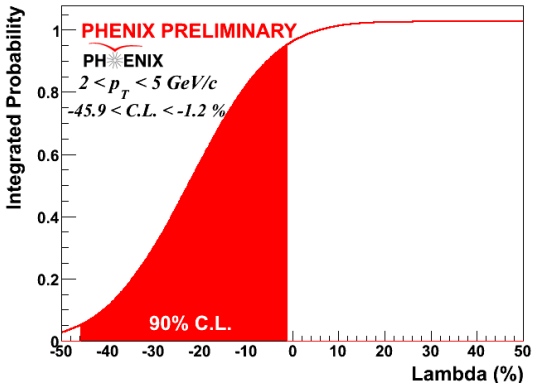


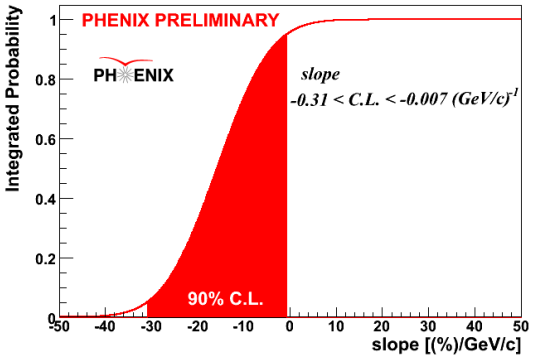




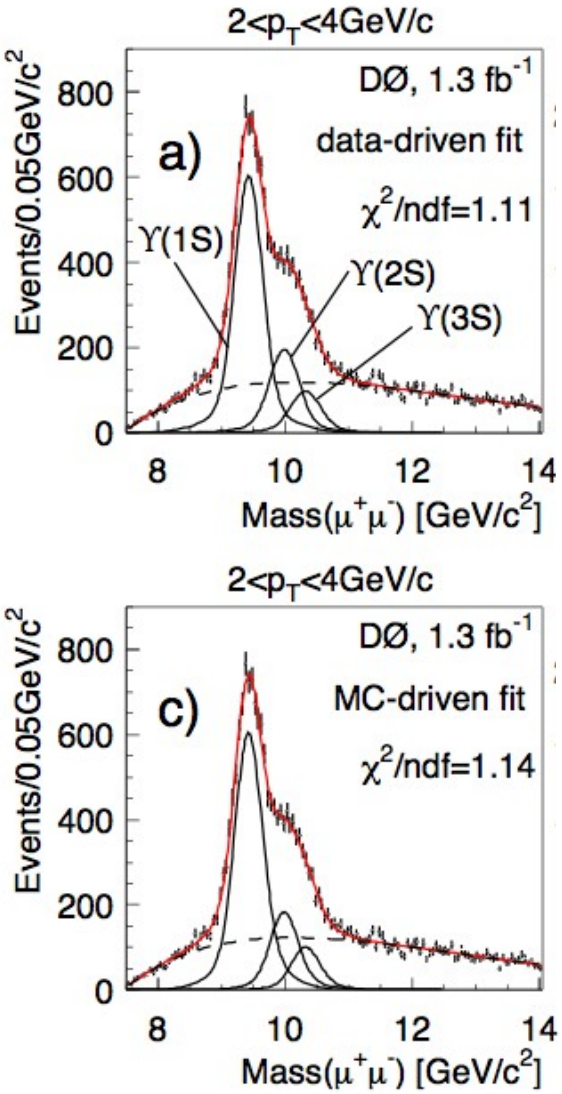


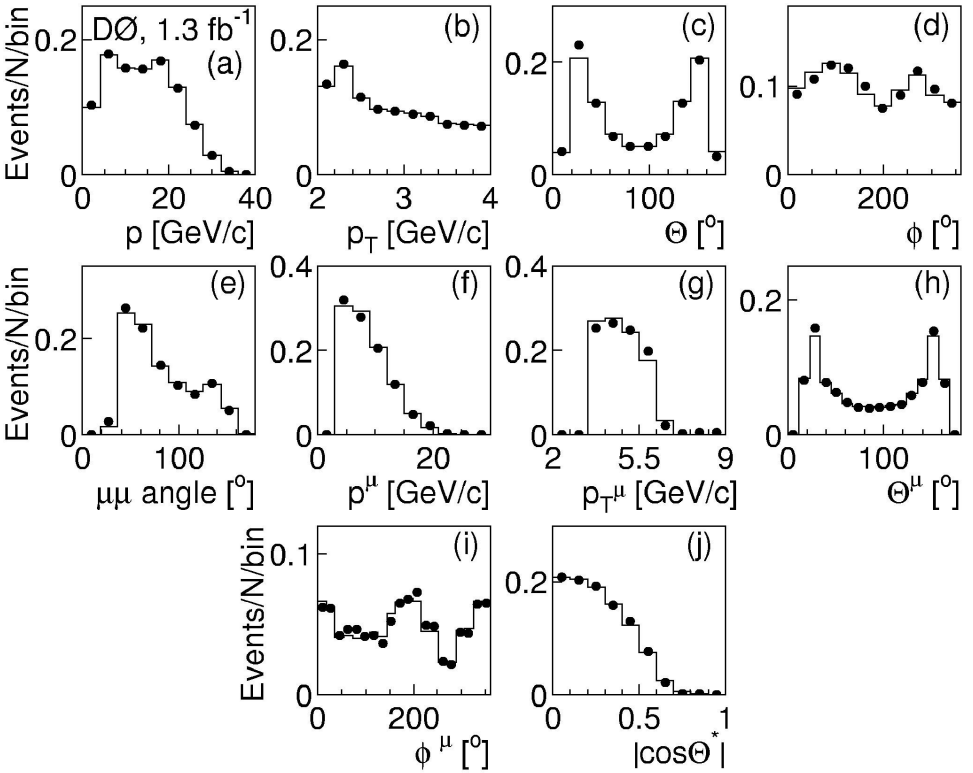






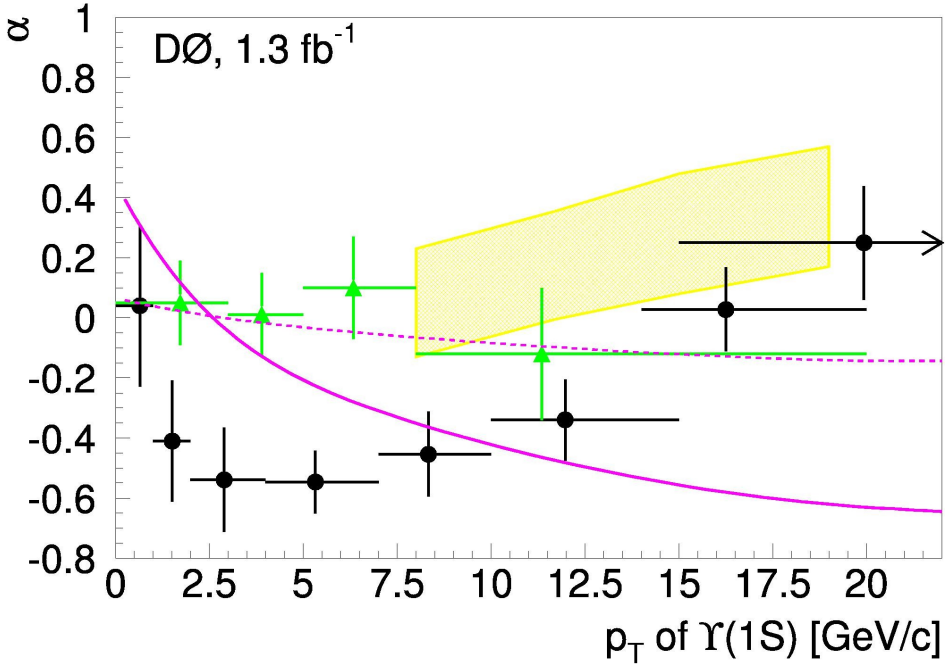
Upsilon polarization measurement in D0

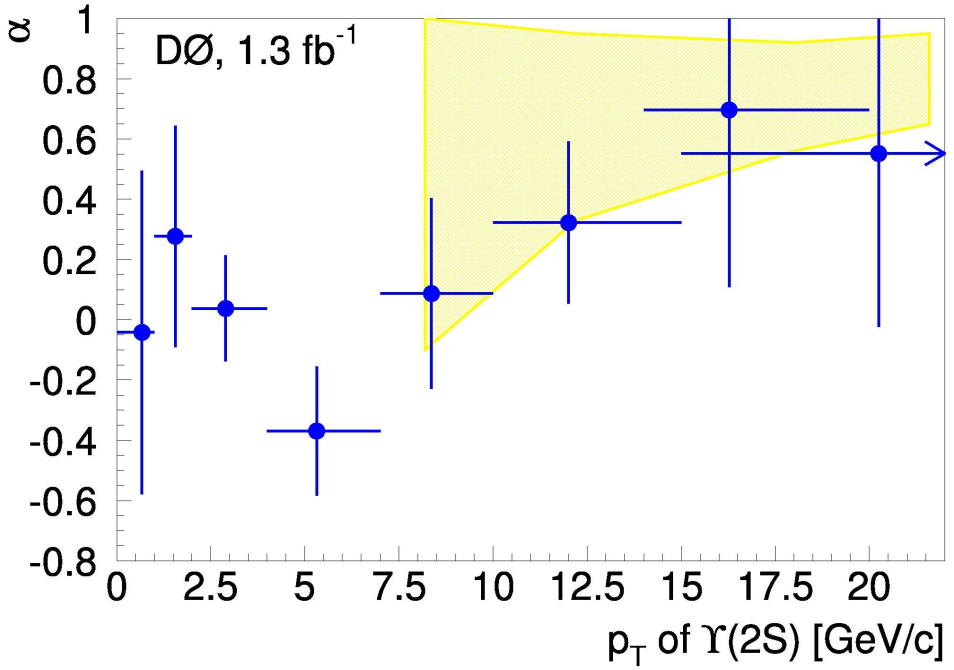




Comparison for Y1S, data (points) and MC (solid histogram) with $2 < p_T < 4$ and muon kinematic distributions.

Upsilon polarization measurement in D0





Band: NRQCDprediction [PRL94,232001],[PRL100,049902(E)]. Curves: limiting cases of kT factorization model [Pis'ma Zh. Eksp. Teor. Fiz.86, 499]

Circles: data. Band: NRQCD prediction. [PRD63,071501]

The previous measurement by CDF of the polarization of Y1S with rapidity y <0.4 is consistent with equal to zero [PRL88,161802]. No explanation why CDF and D0 results are different.

Summary

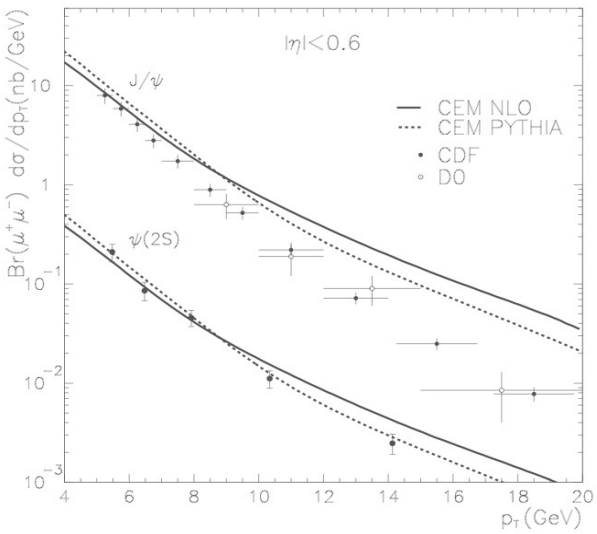
•PHENIX presented J/ψ production measurement (up to 10 GeV/c) in Run 6pp with excellent agreement with the previous Run 5 published results [PRL98:232002,2007] and also the first ψ ' production measurement (up to 7 GeV/c) at RHIC.
•The ψ ' to J/ψ production ratio result shows good agreement with the HERA-B fixed target experiment.
•For the J/ψ polarization measurements in PHENIX, there is a very small chance that the polarization for the highest p_T point is zero or transverse in agreement with recent CSM + 4 point function prediction.
•These data not only constrain production models for heavy quarkonia, but also provide a critical baseline for:

- deuteron + nucleus collisions, to study cold nuclear matter effects;
- heavy ion collisions, to study enhancement or suppression in the QGP.

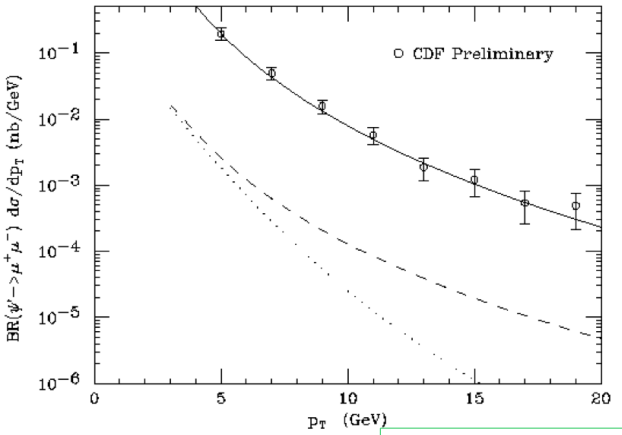
Back up slides

Some hadroproduction models of charmonia

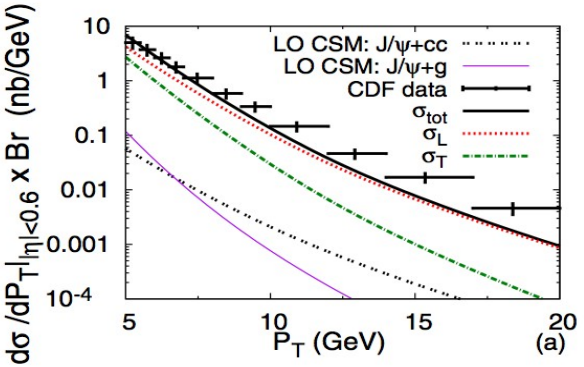
CEM
[Eur.Phys. JC23, 527(2002)]



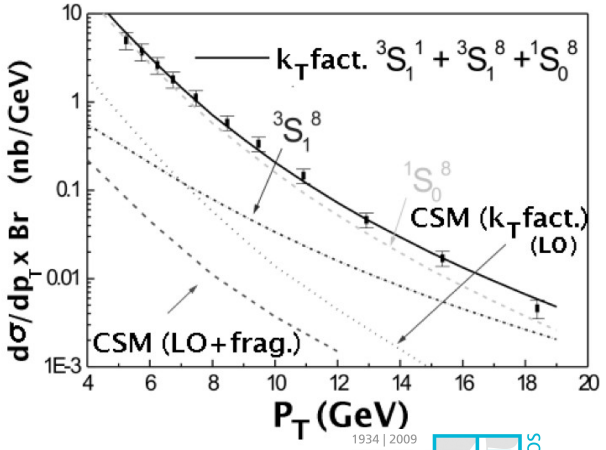
NRQCD + COM
[PRL74, 3327 (1995)]



CSM+4p
[PRL100, 032006 (2008)]



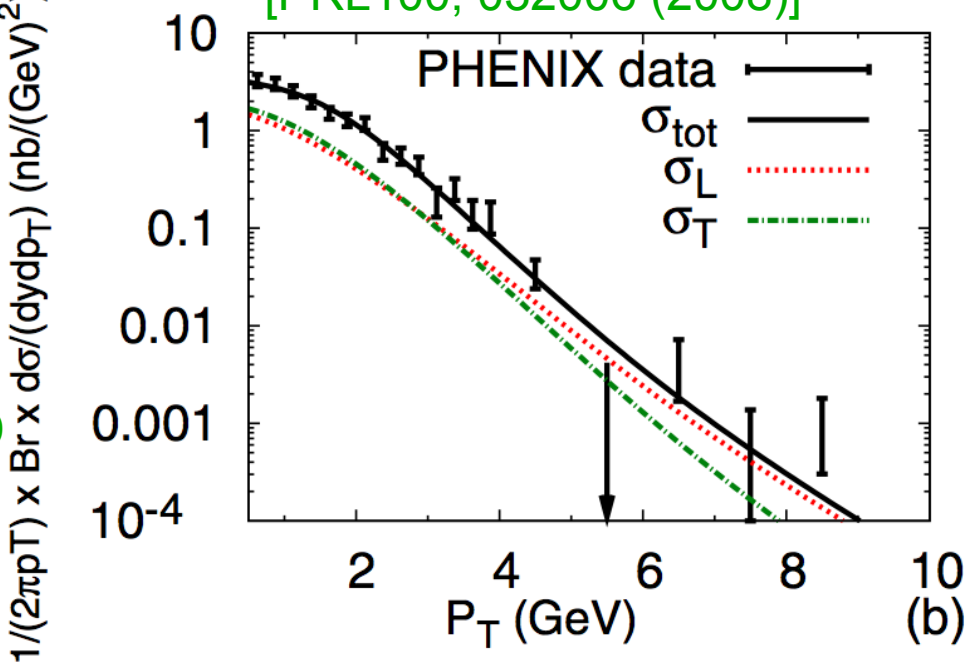
kT factorization
[PRD63, 077501 (2001)]



Predictions for proton-antiproton collisions at $\sqrt{s}$ = 1.8 TeV

Predictions for pp collisions at $\sqrt{s}$ = 200 GeV

CSM+4p
[PRL100, 032006 (2008)]



$\chi_c \rightarrow J/\psi+\gamma \rightarrow e^+e^-\gamma$
(p+p 200GeV, Run-5&6)

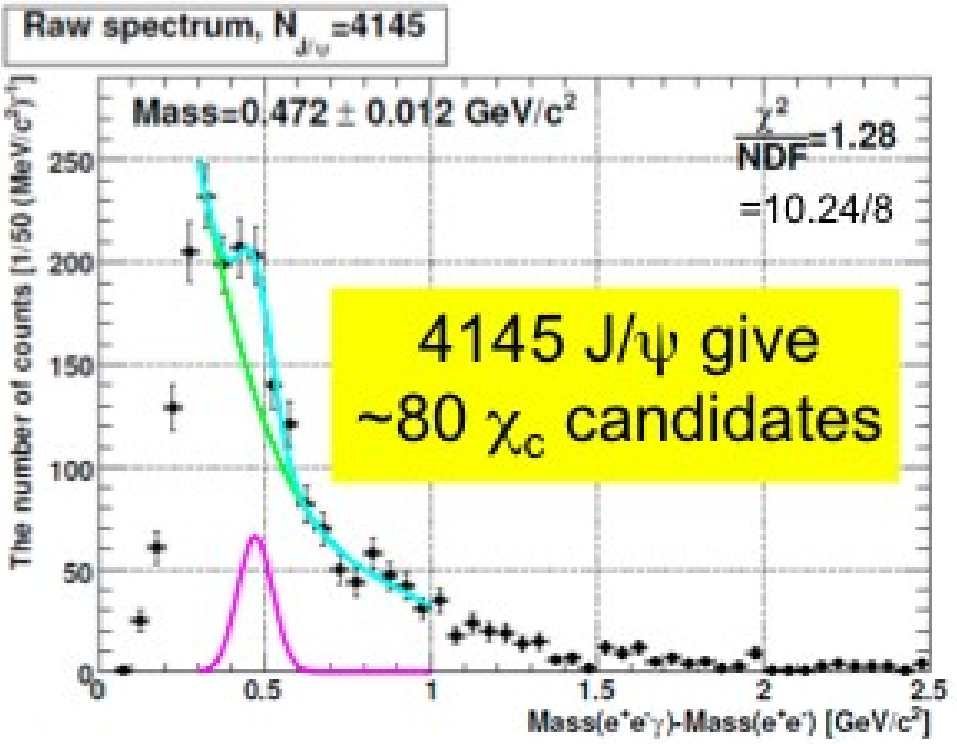
$$R_{\chi_c} = \frac{1}{\sigma(J/\psi)} \sum_{J=1}^{2} \sigma(\chi_{cJ}) BR(\chi_{cJ} \rightarrow J/\psi\,\gamma)$$

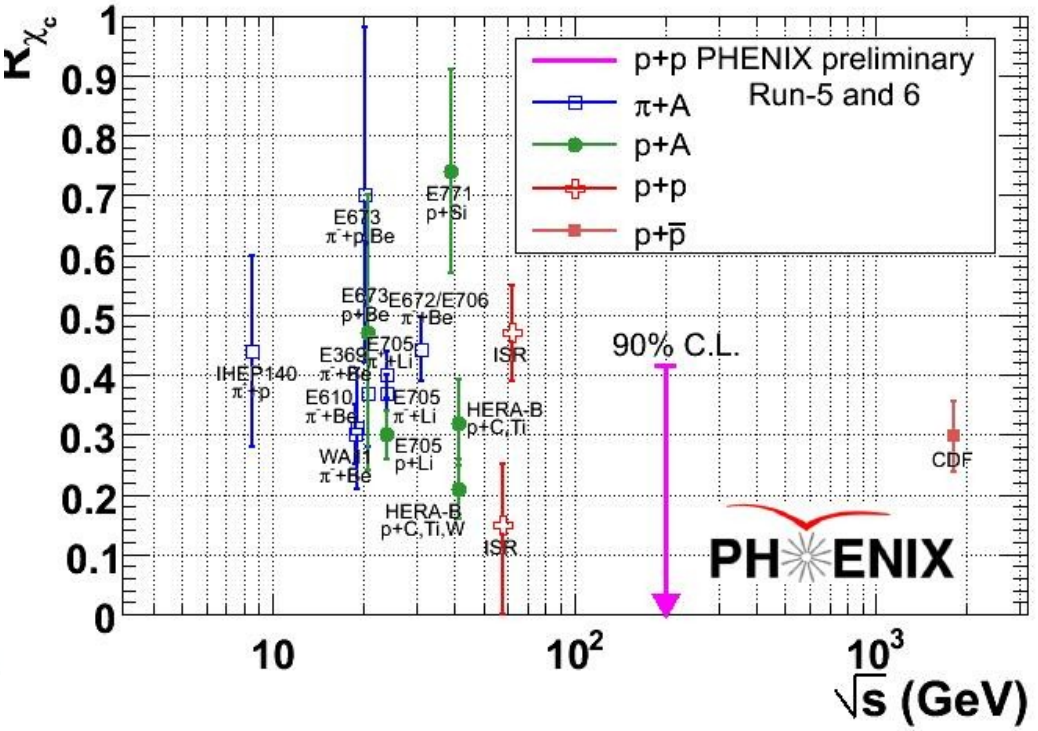
< 0.42 (90% C.L., PHENIX preliminary)

$R(\chi_c)$ =30% ± 8.0 Lattice [Phys.Rev.D64:094015]

PDG 2008 values

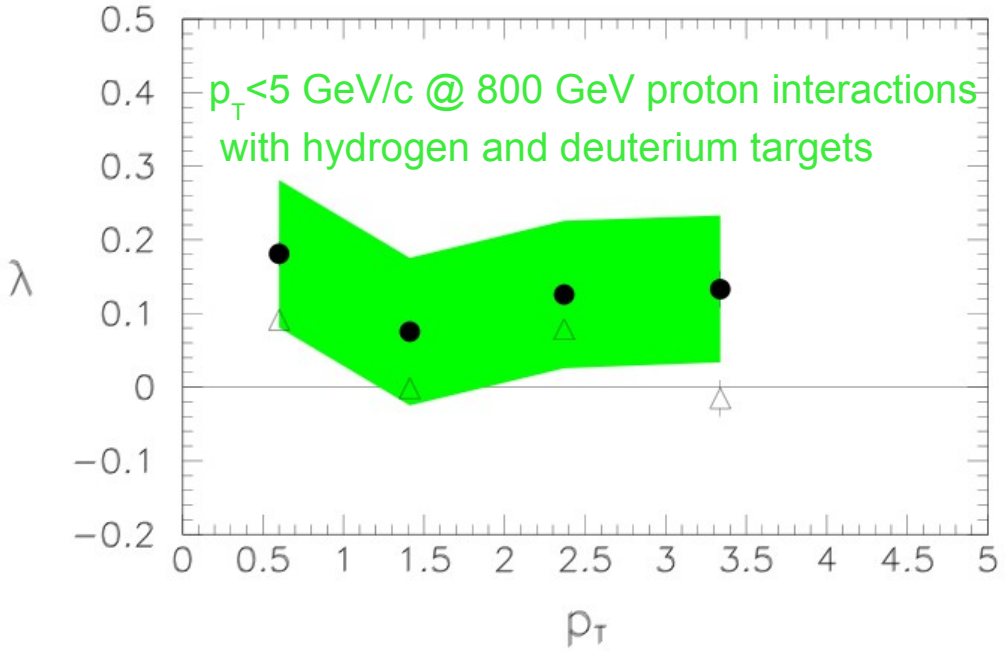
- $BR(\chi_{c0} \rightarrow J/\psi+\gamma)$=1.32 ± 0.11%
  - neglected
- $BR(\chi_{c1} \rightarrow J/\psi+\gamma)$=35.9 ± 1.9%
- $BR(\chi_{c2} \rightarrow J/\psi+\gamma)$=20.3 ± 1.0%





Prior to PHENIX polarization measurement....

J/Ψ polarization parameter in E866



J/Ψ and Ψ ' polarization parameters in CDF

5< p_T< 30 GeV/c
@ 1.96 TeV proton-antiproton collisions